TYPICAL FIELD APPLICATION OF CONSOLID IN TANZANIA

by

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ABSTACT

Consolid soil stabiliser has been used with success at a number of sites in Tanzania. The various possible areas of application of this stabiliser together with the preferred application rates are discussed in this paper.

The paper dwells on the soil evaluation test criteria starting from the field typical representative soil sample selection, the various soil tests carried in the Laboratory of the University of Dar es Salaam and the results obtained.

Evaluation and discussion of these results for the different soils tested is done. Attention is drawn to the parallel for the practical application on the field and reasons are given for the recommendations reached on the strength of the laboratory results.

The relations and parallels observed in the varying soil samples are used to select the "recommended" dosage of the consold chemical to be applied on the field. Preparations necessary before practical application on the site are discussed and the appropriate methods in light of the site conditions are evaluated. The recommended construction method(s) together with appropriate equipment base are discussed.

Continued practical field observations in terms of soil strength improvements obtained at one of the projects are given and the variations from the initial construction time todate are also discussed.

The paper finally discusses the critical theoretical aspects of the consolid stabilisation system and points out the practical and theoretical parallels as obtained in the two case discussed earlier on.

Conclusions are made in terms of the use of consolid as a stabiliser for road construction. Other areas of use where consolid can be used are mentioned and recommendations arising from other areas where it was deployed are stated.

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1.0 INTRODUCTION

As it is the case in nearly every country, Tanzania is confronted with the need to build, improve and increase its road network as a fundamental prerequisite to attain continuous and sustainable development.

In addition, Tanzania has to meet the challenge of creating an infrastructure network not only for transportation of agricultural produce from the hinterland to market places, but also corridors for smooth transportation of goods and services between the neighbouring countries.

However, needs are usually far greater than available resources which makes it necessary to search for economic alternatives both in the construction and maintenance of roads.

Road construction is invariably linked to stabilisation of soils because it is only in rare cases that soils meet requirements set forth by engineers. Soil stabilisation involves changing or improving one or various mechanical properties of a given soil to satisfy given technical specifications.

The traditional method of stabilisation in Tanzania has been granulometry (use of aggregates) that comply with demands on quality, cone size, plasticity etc., and to a lesser degree the use of additives like lime or cement. The former method of stabilisation uses large quantities of granular material whose production and transportation has continued to pose a problem particularly on project costs.

Other additives have slowly found their way into the market as alternatives to the methods used formerly and **Consolid** is one such stabiliser that has accumulated substantial momentum because of its inherent benefits in cost reduction when it comes to soil improvement and maintenance while durability is considerably improved.

This paper therefore seeks to evaluate the effect produced by the Consolid System additive to natural soils of selected road stretches along the Kidatu - Ifakara road located in Morogoro region in order to avoid their replacement against imported soil material.

1.1 General

Consolid is a chemical product developed in the late 1960's to specifically address the problem of stabilisation of soils with poor engineering properties to risk free construction material.

Consolid consists of chemicals which when mixed with soils will reduce the surface tension of the water surrounding the soil particles so that the barrier film is dispersed in order for the surface of the individual particles to associate. This leads to agglomeration of the fines.

Consolid is a catalyst and it does not act chemically with the soil medium, rather on the surface chemistry of the soil particles thereby enhancing its own ability to adhere. It is for this reason that it is called a **catalytic stabiliser.**

1.2 Description of the Products

1.2.1 Introduction to the consolid system

Consolid is refereed to as a system because it constitutes of two products complementing each other in action. In the development of the Consolid System three products were developed for use on pavements. The first of these is added in liquid form and is known as Consolid 444. The choice of the second product is dependent upon the soil type and the moisture condition and may be either conservex, which is a liquid, or solidry, which is a powder.

1.2.2 Consolid 444

Consolid 444 is a liquid chemical product. It acts by releasing the adhering water film surrounding the soil particles. This allows the natural binding power of the soil fines to be enhanced and results in an irreversible agglomeration of the fines by exchange of the electrochemical loading on the soil particles. In this way, there is a reduction in the active soil surface which causes a limited hydrophobic reaction due to pole reversal on the particle surface and a general reduction in the sensitivity of the treated soil against capillarity or water absorption. Since this process occurs on the physico-chemical boundary, the stabilisation effect can be achieved by using the same dosage rate of the chemical for the majority of the soil types.

Consolid is applied in the field at the rate of up to 800 cc per unit volume (m3) of soil. To achieve this low application rate an effective mixing with the soil to be treated is necessary. This is done by diluting the consolid in water preferably by ratio of at least 15:1 to 20:1 with open end in respect of water addition. Because of the small quantities of Consolid to be used the dilution of 20:1 corresponds to hardly one percent moisture to the soil and has rarely an impact on the construction moisture conditioning requirements.

1.2.3 Conservex

Although a treatment with Consolid provides some increased strength and a reduction in capillarity the degree of hydrophobic behaviour achieved is insufficient to prevent unacceptable loss of strength through seepage if the treated soil is exposed to free surface water. To overcome this, the complimentary product Conservex was developed. Conservex is a bituminous product, which is completely dispersible in acidified water. The additional use of conservex in the top layer of the treated soil exposed to surface water further reduces the capillary rise of water. This product is applied in the field in aqueous solution of 0.5% to 1% of the soil weight in the top 10cm of the top layer of the treated soil.

1.2.4 Solidry

Solidry is a dry powdered product. In soils which are pre treated with consolid 444 the powdered particles adhere to the soil particles and plug the particles of the soil thus further reducing the permeability and therefore stabilising the soil. Solidry is used in quantities of 1 to 2% of the soil weight , mainly in the top 10 cm layer of the soil where high resistance against moisture is required. It is supplied in cement like bags or in bulk.

1.2.5 System combinations

With these two combinations of Consolid and Conservex or Consolid and Solidry it is possible to cover all fields of soil stabilisation. Normally Consolid and Conservex are best for dry silt /sandy soils and in non-flooded areas. Consolid and solidry combination is best for wet clayey / silt soils and in flooded areas. Compaction should take place at proctor Optimum or slightly above OMC. In case of excessive moisture content compaction should be avoided to prevent entrapped moisture which will lead to deflection and cracking under traffic. A wearing surfacing is recommended on top of the treated surface to prevent mechanical abrasion.

1.2.6 Areas of application

The consolid system has been used effectively in a wide range of soils in different parts of the world. Other areas of application include;

- Road pavements, road shoulders, railroad embankments, parking lots, airports etc
- Erosion control on embankments, channels, dumps etc.
- Dams, playing grounds, refuse dumps artificial lakes etc
- Mining areas in underground roadways.
- Manufacturing of air dried bricks for low cost housing schemes

2.0 TYPICAL CONSOLID APPLICATION ON STRETCHES OF KIDATU - IFAKARA ROAD

The Ministry of works through its Regional Engineer's office in Morogoro opted to try consolid on some stretches along the Kidatu - Ifakara road. A set of predetermined soil tests of the natural soils were conducted at the soils laboratory of the University of Dar es Salaam and then followed by series of similar tests of the same soils treated with consolid.

2.1 Project Description

The project area lies in Morogoro Region some 190 km south west of Morogoro town off the Mikumi junction on the Morogoro - Iringa highway. The Kidatu - Ifakara road, which is adjoined from Mikumi intersection with a 36 km tarmac stretch to the Morogoro - Iringa highway, is partly of gravel and earth standards. After the El-nino rains this road deteriorated extremely. This road project was part of an emergency spot repair program covering several kilometres in Tanzania after the el-nino rains. The traffic catchment area is primarily agricultural in nature. While the road traverses a potentially fertile and rich agricultural area and natural forests reserve, it is located in a hilly terrain with an over average annual rainfall pattern.

2.2 Sections Earmarked for Stabilisation as Per Design

Kidatu Ifakara road was designed by two different consultants under two portions of approximately 36 km each and awarded to two different contractors for execution. Approximately 3.5 km of the worst sections in both portions was earmarked for stabilisation with consolid. This paper is limited to only three sections of the stabilised areas.
Soil samples were taken from these areas for laboratory analysis.

2.3 Specifications in the Design

2.3.1 Road geometry

A 7.0 m road pavement with a 4% cross falls on either side of the centre line including 0.50 m shoulders each side was specified. Existing alignment was followed.

2.3.2 Drainage structures

Side drains of 1m depth below the formation level and also longitudinal side drains were provided.

2.4 Soil Sampling

2.4.1 Introduction

Prior to sample collection, the type of soil tests to be performed were determined and this in turn established the quantity of soil sample to be collected. The following listed tests were planned for execution: -

i) particle size distribution.
ii) atterberg limits.
(iii) proctor
(iv) CBR under soaked conditions.

Soil samples in their natural state were submitted to the laboratory of the University of Dar es Salaam to undergo predetermined tests (as listed above). These tests were conducted initially on the natural soils and later with the addition of the consolid additives.

2.4.2 Selection of area(s) for sample collection.

The geological configuration of the Kidatu Ifakara areas is in their extension shaped by fine soils of alluvial origin and sediments of fine sand and clay or silt which could have resulted from fluvial deposits. The soils are predominantly composed of clay which can be summarily categorised under the general AASHO classification type A-6, A-7 and A-5.

These samples were collected at three different areas namely at Mang'ula, Kiberege and Sagamaganga at chainages 59km, 71km and 88km respectively. The collection of the samples was limited inside the 1/3 of the pavement width of one of the lanes at a reasonable depth below the surface. Care was taken to eliminate the possibility of inclusion of organic matter as well as any other waste and impurities.

2.4.3 Quantity of samples collected for each lot

Each soil sample required a minimum of 6 CBR tests. Approximately 36 kg of soil material was needed for this test alone. The other predetermined tests (as indicated under 2.4.1) were assumed to have a total material demand not in excess of 4 kg.

2.5 Laboratory Soil Testing

2.5.1 Sample preparation(s)

The samples collected were taken to the laboratory of the University of Dar es Salaam for preparation and subsequent testing. The clayey soil samples were dried in the sun prior to sieving.

2.5.2 Control tests

The engineering parameters for the untreated soils were set as a control for all samples conducted. This control was intended to serve as comparison for any notable improvement in the soil's engineering properties upon the application of the consolid chemical additive. Comparison of the results obtained on the untreated and treated samples supplied the desired information on the effectiveness of the consolid stabiliser. Results of the control tests are tabulated below.

2.5.2.1 Particle size distribution

The particle size distribution obtained for the three samples mentioned are as shown below:

	Sieve Analysis								
	% percentage passing								
Sample origin	Cl+silt	75	150	300	600	1.18	2.36	4.75	9.5
Km 59	29.4	29.4	32.8	39.6	49.3	68	87.4	95.2	98.4
Km 71	25.4	25.4	37.1	56.3	74.7	86.6	93.7	97.1	98.4
Km 88	21.1	21.1	31.4	68.1	84.1	95.3	99.1	100	

2.5.2.2 Atterberg limits

Under these tests the liquid limit, plastic limit and the plasticity index were established as follows:

	Plasticity index			Linear	proctor	
Sample origin	LL	PL	PI	shrinkage	OMC	MDD
Km 59	57	29	28	16	14.9	1.85
Km 71	26	15	11	6	11.3	1.92
Km 88	33	23	10	6	17	1.83

2.5.2.3 CBR tests

This test was conducted on 11/11/1997 on the subgrade material (natural soils). The laboratory standard compaction method with 65 blows and three layers was adopted. The CBR test under dry conditions was not done because it's results would have no relevance to effects that were being sought. The CBR test results in accordance with the sample origin under soaked conditions are summarised in the table below:

Sample origin	Soaked CBR (%) STANDARD COMPACTION
Chainage	untreated
Km 59	9
Km 71	13
Km 88	7

2.6 Testing of Samples Treated with Consolid

2.6.1 General

With the application of the consolid additives the procedure for testing remains the same except that the treated samples must be dried to approximately 50% of the initial moisture content before submitting them to the saturation state (for CBR) or the other tests. This decrease of moisture is recommended to the user as the only departure from the known testing procedures

2.6.1.1 Minimum application

The recommended application rate with consolid additive is 0.4 l / m3 of soil (or 1% in mls) of soil weight) in consolid solution. It is recommended to apply solidry at a rate of 1% of the soil weight.

2.6.1.2 Maximum application

The recommended application rate for consolid C444 is 0.8 l / m3 of soil (or 2% (in mls) per kg of soil that is being treated) while solidry is recommended at a rate of 2% of the weight of the soil (see 1.2.3).

2.6.2 Tests with minimum and maximum application

The soil samples were tested with both Consolid additives applying the recommended rates for both minimum as well as maximum. The results for the different samples is included in the table below:

Sample origin	Soaked CBR Treated with C444 and SD	
chainage	Minimum application	Maximum application
Km 59	18	40
Km 71	28	37
Km 88	17	23

2.7 Evaluation of test results

2.7.1 Introduction

Despite the size of the samples tested, a very important and decisive indicator was visible in the bearing strength of the soil samples. This picture is clearer when results of the same soil sample for the untreated natural soils and the ones treated with consolid chemicals are observed. The control test for the soil samples gave untreated natural soil soaked CBR values ranging between 7% and 13% while those of treated soils ranged from 23% to 40%.

2.7.2 Discussion of results

The properties investigated, such as bearing strength (CBR) when compared with the results obtained on the treated soils indicated that consolid had a tremendous effect on the soil. These results reveal that use of Consolid system causes the soaked CBRs to increase by a factor of 2 for the minimum application while the maximum application showed an increase by a factor of three and above. In general it could be said that by using consolid system, certain relations between the behaviour of untreated soils and those of treated soils become very distinct.

2.7.3 Comparing the lab situation to practical field application

By adopting the maximum application out in the field it is expected that the CBRs for the soils on all sections selected would be improved by a factor of three and above as indicated in the previous tests.

2.7.4 Recommendations for field application based on results obtained

From the test results, the maximum application rate was recommended. This rate of application will ensure an increase in the CBR by a factor of three times and above. However, if blending the insitu soils will be done by adding some of the missing fractions then additional improvement will be expected in the given results. The natural soils picked from the project site had very little or almost no coarse particles.

2.7.5 Inferences to expected field results out of above recommendations

Under lab conditions the quantities of chemical calculated using the recommended application rates is very small to mix in the sample for testing. It is however envisaged that the practical application will entail using larger quantities of material and hence simplify the mixing operation thus ensuring uniformity which will in turn ensure even better results.

2.8 Practical Application in the Field

2.8.1 General

The previous laboratory test results was a guidance of what is to be expected out on the field. However it is expected that the field situation will yield even better results due to the following reasons:

- the dosage of the small amount of chemical used in the lab is difficult to mix in a small sample
- uniformity in the mixing operation which ensures better contact of individual soil particles to the consolid chemicals
- The drying situation for the CBR samples will not be necessary out on the field because of a uniform exposure of the whole road surface to the natural conditions of weather
- After initial compaction flowing traffic will continue to impose secondary compaction which will continue to improve the already attained good CBR values.

2.8.2 Preparations for establishing chemical inputs

2.8.2.1 Area to be stabilised

Section	Length (m)	Width of pavement (m)	Effective area for stabilisation A (m2)
Mang'ula	800	7	5600
Kibelege	250+150	7	2800
Sagamaganga	150	7	1050

2.8 2.2 Establishing quantity of chemicals required

Section	Effective area for stabilisation A (m2)	Soil weight (tons)	Quantity of chemicals required Minimum application		Quantity of chemicals required Maximum application	
			0.1 lit per m2 area	1%of soil weight	0.2 lit per m2 area	2%of soil weight
			Consolid (C444) (Litres)	Solidry (SD) (Tons)	Consolid (C444) (litres)	Solidry (SD) (tons)
Mang'ula	5600	2800	560	11.2	1120	22.4
Kibelege	2800	1400	280	5.6	560	11.2
Sagamagan ga	1050	525	105	2.1	210	4.2

From the laboratory results the maximum application rate for C444 of 0.2 l /m2 of the road was recommended while solidry was applied only to the top 10 cm of the pavement at the maximum application rate of 4kg/m2 of the road. The Solidry is spread evenly on the surface and then mixed thoroughly in the layer with the appropriate equipment.

2.8.3 Placing the order for the chemicals and the delivery logistics

The established chemical quantities must be ordered well in advance during the planing process to ensure that delivery goes hand in hand with the execution of the works. Accordingly the delivery timetable sets a lead time of three months ahead of the delivery of the chemicals to the planned site. This must be planned in the works schedule and considered in the execution planning.

2.8.3.1 Packaging

The liquid chemicals are delivered in drums of 200 litres while the solidry is delivered in double layer polyethylene bags of 50 kg each. This simplifies handling at site particularly because handling is mostly manual.

2.8.3.2 Transporting to site

The chemicals supply contract is based on ex works delivery terms. Delivery to site must be considered in the works contract which can be anywhere within the borders of Tanzania.

2.8.3.3 Receiving chemicals at site and safety requirements

The solidry is bulky and it is recommended that a temporary storage facility be provided at the site if it will not be put to use immediately.

-Like cement or lime the Solidry requires handling precautions. It is recommended that all persons coming in contact with the chemicals be provided with safety gear like hand gloves, dust masks and if possible boots.

2.8.4 Recommended method of construction

A mix in place construction method was the best alternative considering the volume of works. This method reduces material handling and transportation costs. The first 15cm out of 25 cm soil layer (60%) was mixed with the correct quantity of compaction water containing 60 % of the required consolid 444 solution. This was then compacted with the sheep foot roller. The remaining top 10 cm was put in place and the right amount of solidry was spread and mixed-in thoroughly before applying the rest of the 40% consold 444 diluted with the correct amount of optimum water. Compaction with sheep foot roller by trimming to level with a grader before final compaction with disc roller is done.

2.9.4.2 Mixing in the calculated SD quantities in the soil

The bags containing SD were opened and the quantity was spread by manual labour over the pulverised soil layer of 10 cm thickness across the width of pavement . With the disc harrow the SD was mixed-in to the required depth. The second operation of application of the rest C444 in the 10 cm layer thickness was followed by compaction with a sheep foot roller.

Fig. 1: Application of Solidry to one of the lanes

Fig 2 Preparation of Solidry bags before spreading on the left lane (Location km 59 at Mang'ula) Note the soil material to be mixed with solidry on the left edge of the lane

2.9.4.3 Grading to required levels and compaction

The surface was finally leveled using a grader and compacted with a disc roller.

Fig.3: Grading to final levels before compaction. The right lane is completed and free for traffic flow

2.9.5 Taking samples for testing

After completion samples were taken for testing to find the correlation of the lab situation in relation to the field.

3.0 HIGHLIGHTS OF THE KIDATU IFAKARA EXPERIENCE

3.1General

The construction process was simple and fast. Because no curing is necessary traffic was allowed on the finished lane upon commencing works on the untreated lane.

3.2 Lane allocation

The procedure was to take one lane at a time while the other lane remained free for traffic.

Fig. 4: Construction proceeding lanewise. Note the the equipment in use

3.3 Diversion and Allowing Traffic on Treated Sections

Traffic is allowed on treated lane immediately. This improves attained densities and enhances the compaction. In this context diversion was not necessary as would be the case with the use of binders as Stabilisers

3.4 Continued Monitoring of Treated Sections

	Mang'ula		Mang'ula		Maili 100	
date	20/07/1999		10/10/1999		10/07/1999	
	untreated	treated	Treated Location 1	Treated location 2	untreated	treated
Plasticity index PI	19	11	8	14	24	24
Classification	A-7-6		A-2-4	A-6	A-7-6	A-7-6
MDD (kg/m3)	1830	1944	2070	2024	1910	1940
OMC (%)	12.6	11.6	9	10.3	12.5	11.2
CBR (%)	13	65	78	70	14	46
Swell (%)	0.40	0.1	0.12	0.11	0.4	0.22

The effect of the consolid additives can be seen to considerably improve various properties of the soil.

- increase of the bearing strength predicted in the laboratory has also been confirmed in the practical field application as seen in the table above.
- reduction in the swell properties of the soils.
- reduction in the PI values.
- increased dry densities while the corresponding optimum water content is reduced.

Fig. 5: Monitoring of treated sections after construction

Fig 6 Treated section on Sagamaganga

4.0 CONSOLID ON BULYANKHULU MINE TOWN ROADS

4.1 Introduction

Kahama mining Corporation limited is developing a mine at Bulyankhulu in Kahama district south of Lake Victoria. Like all mines Bulyankkhulu had no road infrastructure. Kahama Mining has already opened up the mining town to the existing infrastructure and is continuing to do so. Bulyankhulu has more than 20 km of roads in the mine township. All the roads are built using the natural occurring soils with some loose gravel on top.

4.2 Project Location Area

Bulyankhulu is located some 150 km from Kahama town and 60 km south of Lake Victoria. Kahama Mining has decided to use Consolid in stabilising their roads and eventually their airstrip in their mine.

4.3 Selection of Consolid as Stabiliser

Unlike the Kidatu Ifakara project, consolid was selected as stabiliser for the Bulyankhulu mining roads having considered a whole range of possible alternatives.

4.4 Laboratory Tests

Kahama Mining delivered soil samples for testing at the University of Dar es Salaam. On examination the natural occurring soil had in excess of 65 % clay, silt and sand .All fractions were well represented.

The laboratory soil sample test results of the submitted sample are included in the table below:

Soil properties	Untreated soil	Treated with consolid min application (1% C444 + 1% SD)	Treated with consolid max. application (2% C444 + 2% SD)
PI	18		
OMC	10.3	9.5	9
MDD	2.0	2.31	2.35
CBR	70	260	Not measurable

4.5 Qualifying the Selection of the Dosage of Chemicals Recommended

Although the CBR of the untreated soil was good, the plasticity index on the other hand was high and this could lead to loss of strength under wet conditions. The CBR obtained under minimum application was, for the purpose of the project extremely good. The CBR value for maximum application was beyond the calibrated limit of the lab equipment which was used. In this example it would not make sense to adopt the maximum application.

4.6 Construction Methods to be Adopted

As was the case for the Kidatu -Ifakara project, the mix in place method which limits material handling was recommended. Consolid chemicals applied at minimum application rate of 1% C444 for a layer thickness of 25cm solidry will achieve high CBR values. To protect this investment it was further recommended to seal the surface with a double surface dressing.

4.7 Concluding Remarks

Unlike the Kidatu -Ifakara experience, in this case it was possible to mobilise high strengths through the use of the minimum application rates of the consolid system. These strengths meet all specifications required for any pavement with high traffic loading. It is also possible with the consolid system to achieve the same conditions as those in Ifakara by blending the soils with some fractions which were missing particularly the coarse fractions.

5.0 COMPARISON TO CONVENTIONAL BINDERS USED AS STABILISERS

In the beginning of this paper it has been indicated that the consolid system is catalytic in nature and its action only enhances the soil particles themselves to mobilise the properties desirable to the engineer.

Binders like lime and cement tend to glue the soil particles together. Once soils have been treated with any of these binders or consolid they will need to be well compacted under laid down conditions (optimum moisture content).

As we have observed in Ifakara such sections treated with consolid can carry traffic immediately. With binders there is a requirement for curing which might lead to provision of temporary works like diversions.

In the normal process of working, binders hydrate. The hydration process in binders is associated with heat development. Heat causes expansion (volume increase) and this partly destroys the initial compaction as well as the achieved dry density.

In process of working consolid does none of these, but it gives the treated soils an impermeability effect which improves the internal angle of friction and with it also the resistance against shearing. The immpermeability effect ensures dry strengths and eliminates softening due to water penetration . This acquired behaviour through treatment is unknown in the use of conventional binders.

Apart from the fact that consolid treated soils can be stock piled without loss of effectiveness which gives it additionally the possibility of the mix - in plant method of construction, the treatment of soils with consolid is permanent and these soils will never regain their initial natural properties.

This implies that the soil properties gained under treatment with consolid are permanent, irreversible and hence sustainable. These properties can only be improved further with continued secondary compaction under traffic flow. This is also not achievable with conventional binders.

From the above reasons, it is not correct to make a direct comparison between stabilising with use of binders on one side and use of consolid on the other.

Fig.7: A typical preparation of the area to be treated

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